

**Modeling tropospheric impacts of the 2011 record  
Arctic ozone hole  
(Event attribution study to determine causes of  
record positive surface NAM index in spring of 2011)**

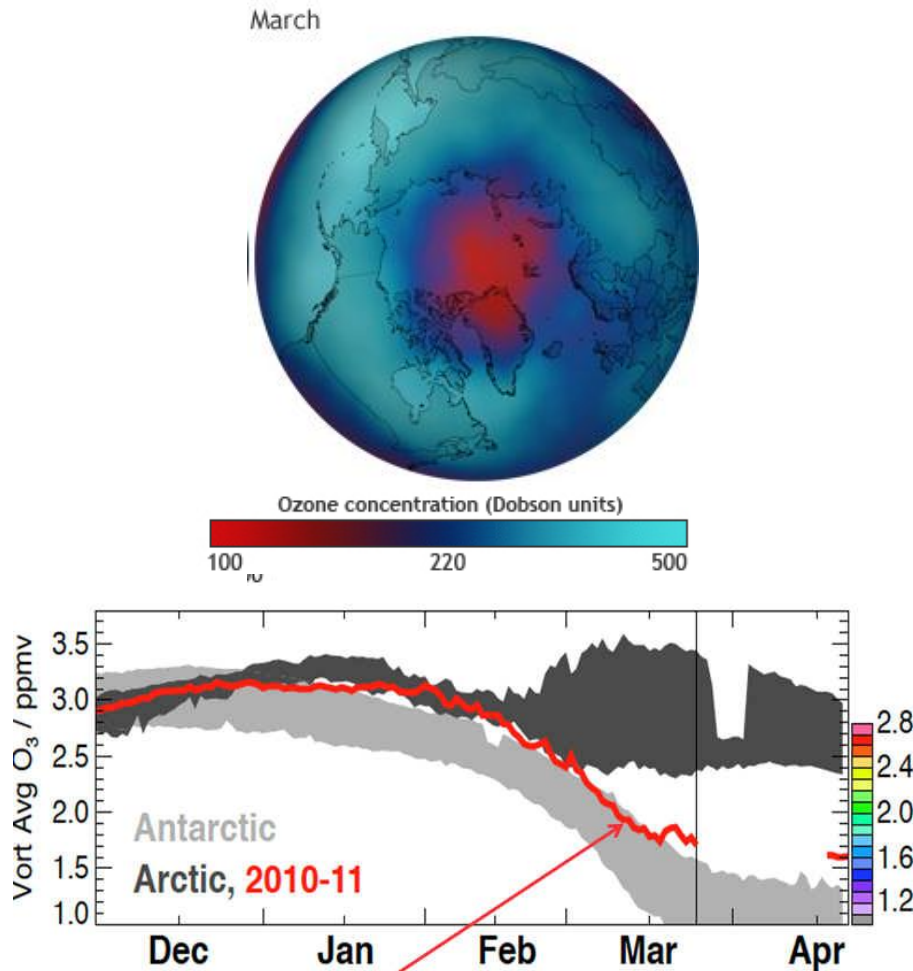
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Colorado and NOAA/ESRL/PSD)**

**In collaboration with Alexey Karpechko  
(FMI) and Elisa Manzini (MPI Hamburg)**

# Motivation

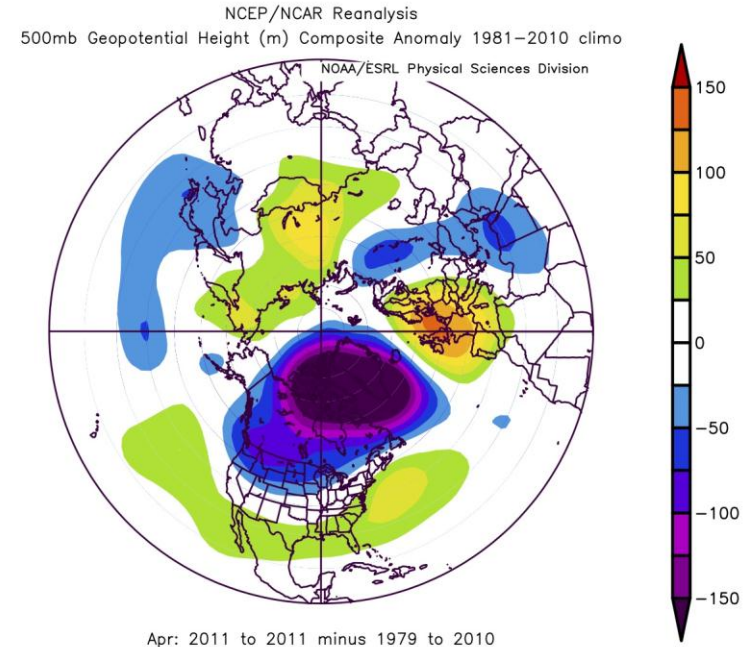
- Stratospheric and tropospheric circulations are closely coupled both upward and downward
- Stratospheric events impact tropospheric weather and climate
  - Major stratospheric sudden warming events are followed by negative Northern Hemisphere Annular Mode events that can last up to two months.
  - Over the last three decades, Antarctic ozone depletion caused a shift of the Southern Hemisphere annular mode toward its positive phase during summer.
- The spring of 2011 was characterized by record climate events in both the stratosphere and troposphere - Are they connected?

# Record Arctic ozone loss in 2011 comparable in size to average Antarctic ozone hole

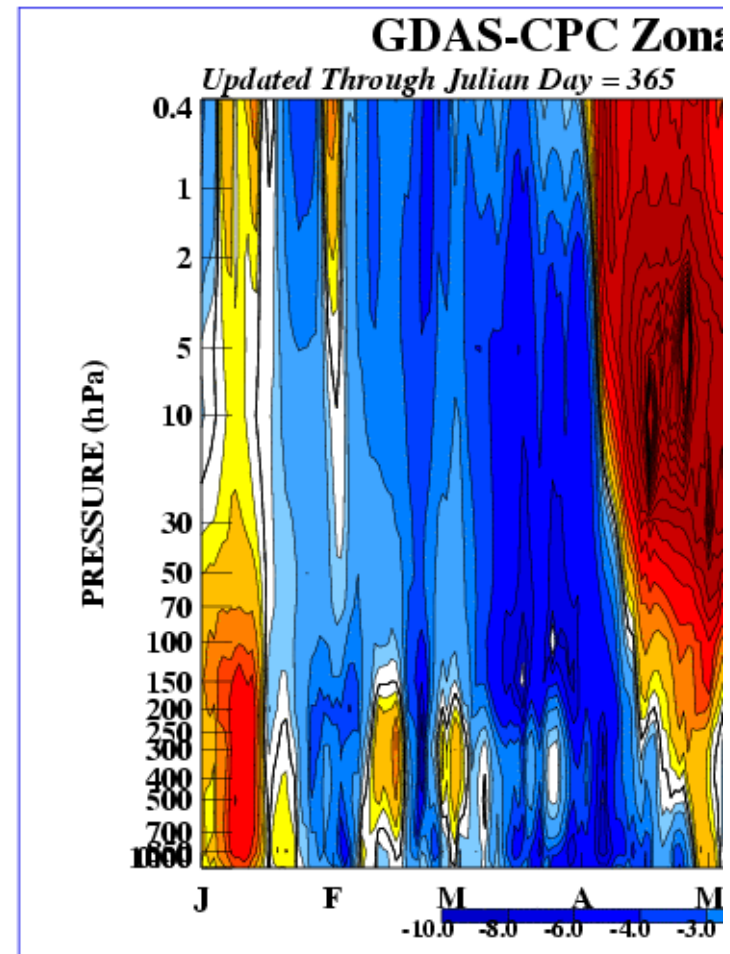
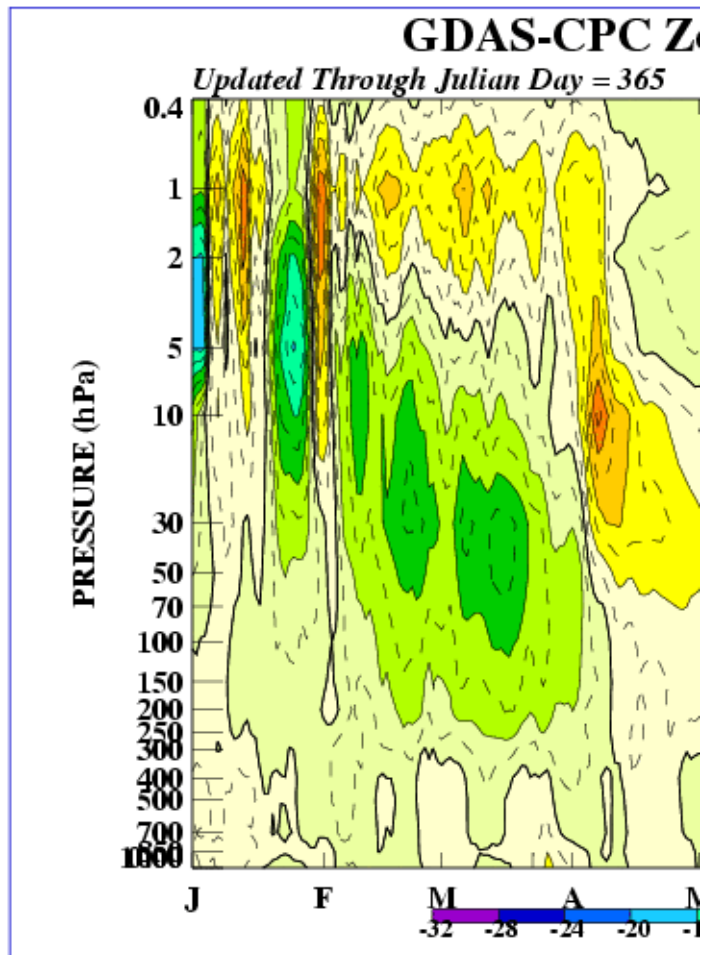


**Arctic Ozone in 2011** was outside the range of the 2005-2010 winter observations, and almost as low as Antarctic ozone.

# Record positive value of NAM/NAO index in April 2011



# Observed evolution of polar cap temperatures and geopotential heights in 2011



NAO: -0.88 0.70 0.61 2.48\*

NAM: -1.68 1.57 1.42 2.27\*

\*Record value since 1950

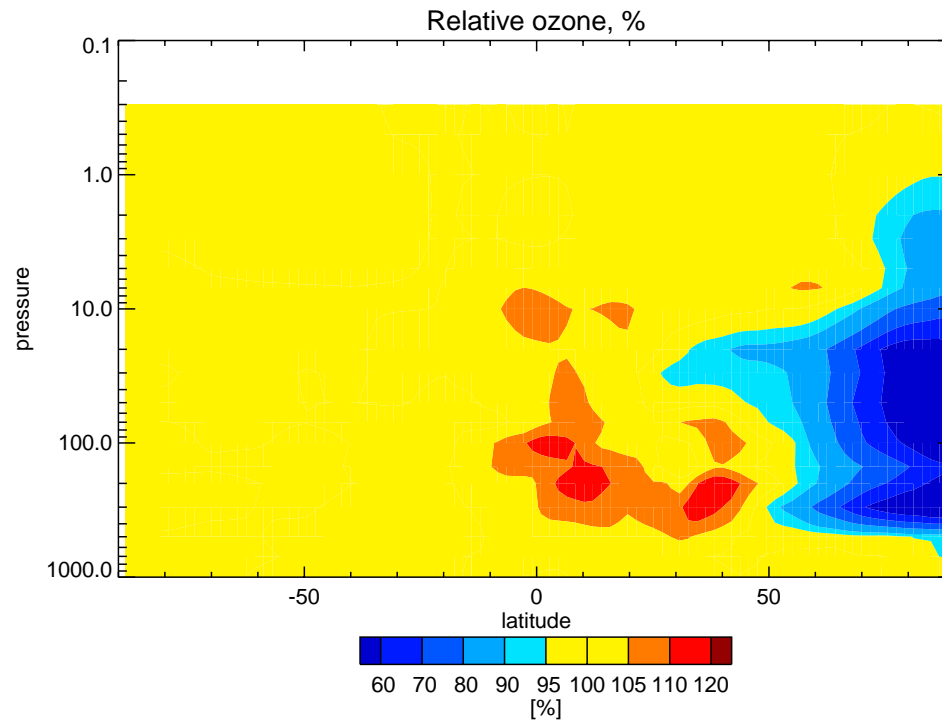
**Was the Arctic ozone hole the  
primary driver of the record  
tropospheric circulation event?**

# Modeling study in the spirit of the event attribution approach

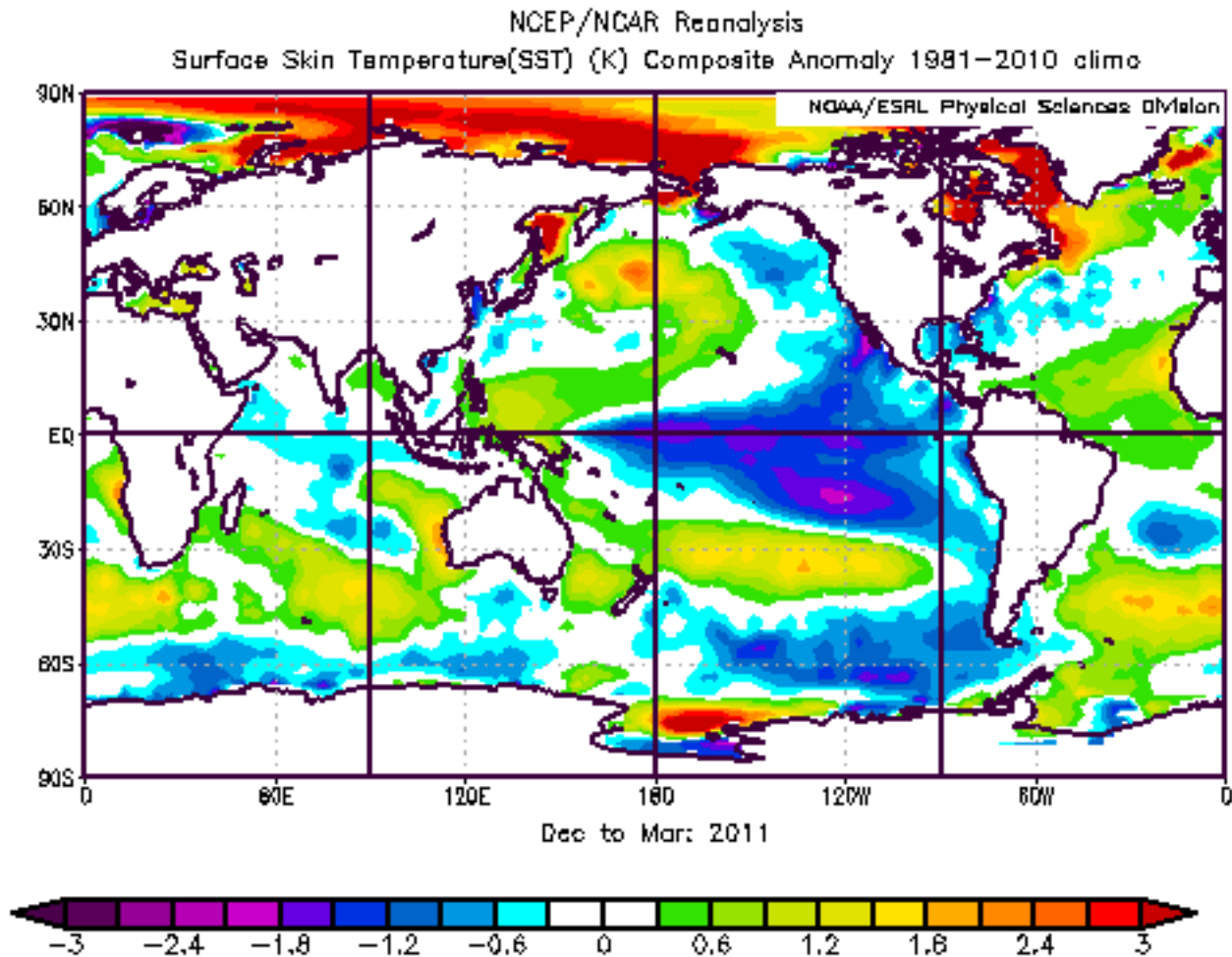
Four experiments with AGCM MA-ECHAM5 :

- CTRL: 50 years; AMIP2 SST/SIC clim.; Fortuin-Kelder O3 clim.
- R-O3: 50 runs from Sep 1 to Apr 30; SST/SIC as in CTRL; Fortuin- Kelder O3 + MERRA O3 anomaly 2010/2011 for NH
- R-SST: 50 runs from Sep 1 to Apr 30; AMIP2 SST/SIC climatology + HadISST 2010/2011 anomaly; O3 as in CTRL
- R-ALL: 50 runs from Sep 1 to Apr 30; SST/SIC as in R-SST; O3 as in R-O3

# Prescribed March Ozone anomaly



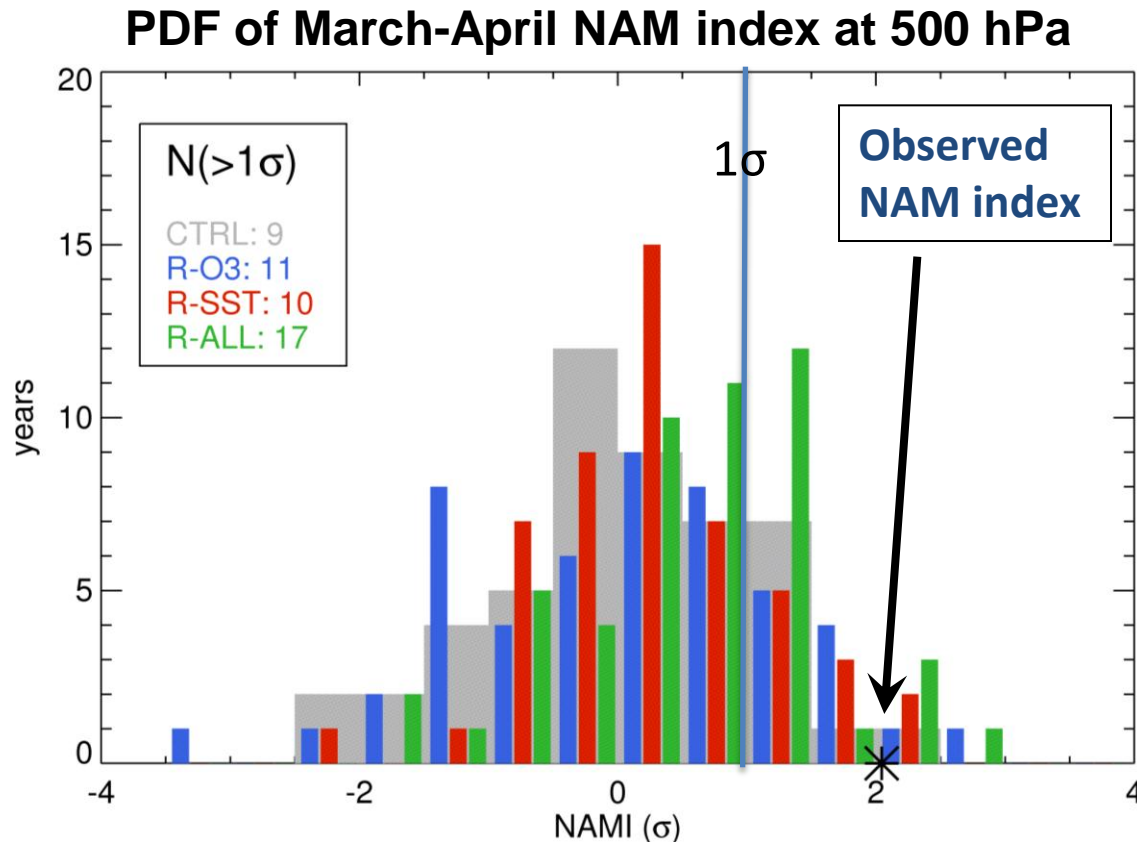
# Dec-Mar 2010/2011 SST anomalies



# Monthly evolution of mid-latitude (50-70N) zonal wind response

Downward progression of positive mid-latitude zonal mean zonal wind anomalies during March/April which is strongest in the R-All simulation

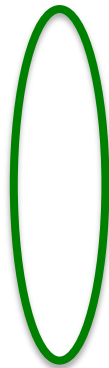
# NAM impact during mid-March to mid-April



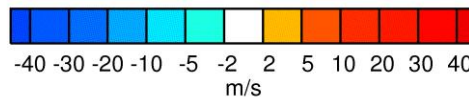
- Shift of NAM index toward positive phase in all three experiments with shift being largest in R-All
- The combined forcing by the observed ozone and SST anomalies
  - Doubles the probability of large ( $> 1\sigma$ ) positive NAM events in March/April in the model

# What did enhance the possibility of occurrence of most extreme NAM events in the model?

All

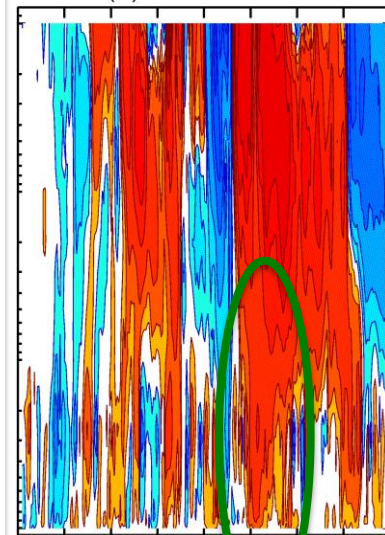


Pressure (hPa)



ERA-Interim

(b) ERA-Interim



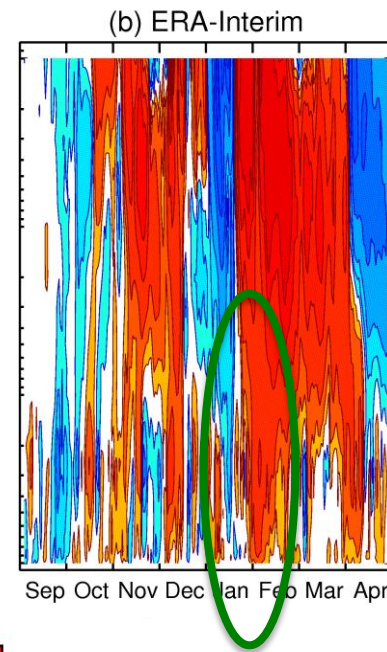
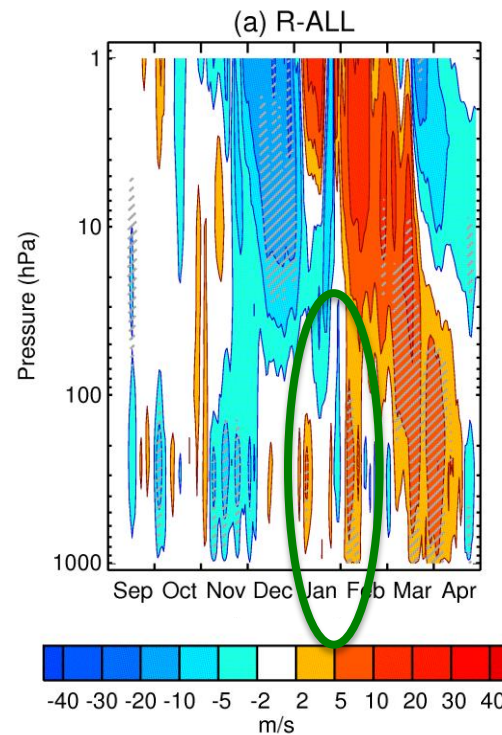
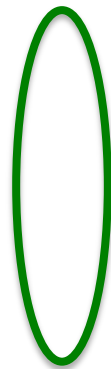
Sep Oct Nov Dec Jan Feb Mar Apr

# What did enhance the possibility of occurrence of most extreme NAM events in the model?

All

4 most extreme  
NAM events

ERA-Interim



Tropospheric pre-conditioning via positive NAM phase in February in consistency with observations

# Summary

- Arctic ozone losses reached record 80% at 18-20 km by early spring 2011
- It was followed by record positive NAM conditions in the troposphere
- A climate model forced by the observed ozone depletion shows only weak positive NAM response
- The combined forcing by ozone depletion and lower boundary conditions doubled the chance for an occurrence of an extreme NAM event
- Pre-conditioned troposphere is likely a pre-requisite for extreme spring NAM response

# Implications

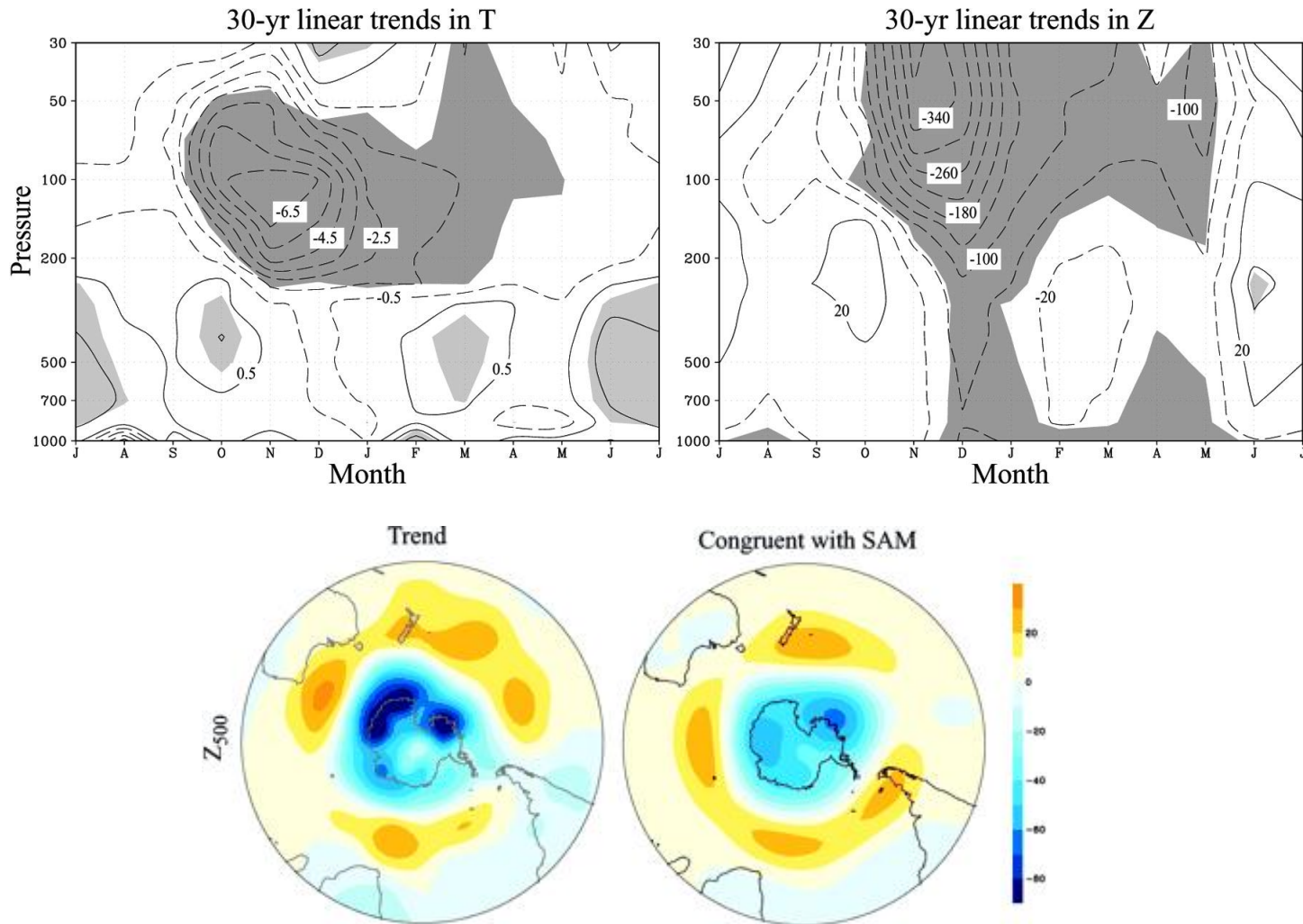
- Coupled ocean-troposphere-stratosphere system needed to explain the occurrence of tropospheric circulation extremes in spring 2011
- Improving predictability of such events requires models that include stratospheric ozone chemistry to properly simulate chemistry-climate feedbacks
- Ozone loss in 2011 was initiated by very cold stratospheric winter (Jan-Feb) polar vortex leading to the formation of PSCs with subsequent ozone loss -  
>Talk of C. Long for capability of CFSv2 to simulate observed extreme polar stratospheric temperature events

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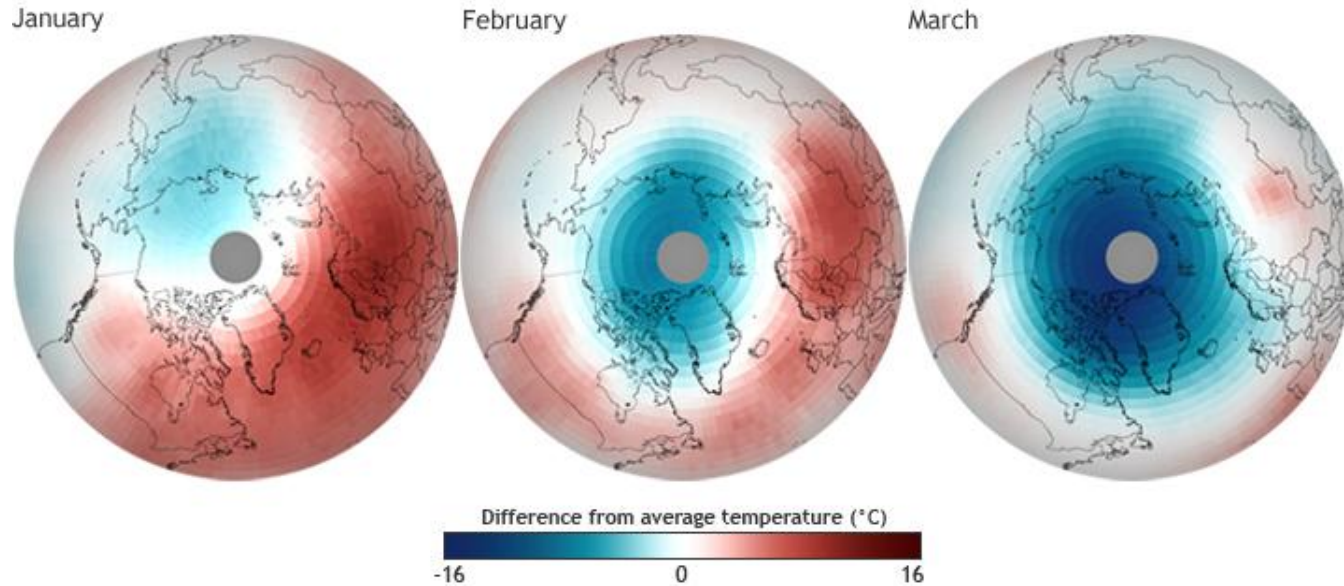
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**>Talk of C. Long for capability of CFSv2 to simulate observed extreme polar stratospheric temperature events**

# Backup Slides

# In the SH, Antarctic Ozone hole strongly impacted tropospheric circulation during summer



# Lower stratosphere temperature in winter 2011



Number of days below threshold for activation of Polar Stratospheric Clouds over several lower stratospheric levels combined

